Evidence for Dynamical Fragment Production?

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Toke *et al.* claimed that, above a certain saturation energy, the intermediate-mass fragments (IMF) from ^{136}Xe+^{209}Bi at E/A=28 MeV are emitted by a dynamical process, via a new mode of energy dissipation [1]. A dynamical mechanism was invoked based partly upon the alleged failure of statistical models to describe: 1) the saturation of the average light charged particle (LCP) multiplicity, neutron multiplicity (m_n), and LCP transverse energy ($E_t^{\rm LCP}$) as a function of IMF multiplicity ($m_{\rm IMF}$); and 2) the "absence of competition" which is inferred partly from the different behavior of the transverse energy of the IMFs ($E_t^{\rm IMF}$) compared to $E_t^{\rm LCP}$ as a function of $m_{\rm IMF}$. It occurred to us that this alleged "evidence" for dynamical behavior is actually an intrinsic feature of any *statistical* model.

Consider the statistical emission of two particle types with barriers B_1 and B_2 (and $B_2 > B_1$). Assume the emission probabilities are $p_i \propto \exp\left[-B_i/T\right]$ $(i = 1,2)$ with $p_1 + p_2 = 1$. With the temperature T characterized in terms of the total multiplicity $n_{\rm tot} = n_1 + n_2 = \alpha T$, and ignoring mass conservation, the solution for $\langle n_1 \rangle$ as a function of n_2 can be calculated for a distribution of temperatures where the number of events at a given T is $\propto (T - T_{\rm max})^2$.

The solution of this model is shown in Fig. 1 for B_1=8, B_2=24, $T_{\rm max}$=10 and $\alpha = 2$. This behavior is similar to that observed in ref. [1]. In this calculation, the value of $\langle n_2 \rangle$ at $T_{\rm max}$ ($\langle n_2 \rangle_{\rm max}$) is approximately 3.4 (arrow) and represents the largest average multiplicity of species two. Therefore, one expects that $\langle n_1 \rangle$ saturates at a value of $n_2 \approx 3$. The larger values of n_2 come from the tail of the multiplicity distribution from events with $T \approx T_{\rm max}$. In other words, n_2 is a poor measure of T for $n_2 < \langle n_2 \rangle_{\rm max}$ and is rather insensitive to T for $n_2 > \langle n_2 \rangle_{\rm max}$.

Statistical models show similar trends. In Fig. 1, $\langle m_n \rangle$ and $\langle m_{\rm LCP} \rangle$ are shown as a function of $m_{\rm IMF}$ for a gold nucleus decay calculated with the statistical multifragmentation model (SMM) [3] and a distribution of excitation energies ϵ^* up to 6 MeV/nucleon. The values of $\langle m_{\rm LCP} \rangle$ and $\langle m_n \rangle$ saturate at $m_{\rm IMF} \approx$ 4-5, consistent with $\langle m_{\rm IMF} \rangle_{\rm max}$ (arrow) for the maximum ϵ^* calculated.

Consequently, one can reexamine the trends observed in ref. [1]. The values of $\langle m_{\rm LCP} \rangle$ and $\langle m_n \rangle$ saturate at $m_{\rm IMF} \approx 3$. One expects therefore that, as a function of some measure of excitation energy (e.g., charged particle multiplicity), the $\langle m_{\rm IMF} \rangle$ would also yield $\langle m_{\rm IMF} \rangle_{\rm max} \approx$ 3. This is the case [2]. Furthermore, raising the energy available to the system should give both larger saturation values of $\langle m_n \rangle$ and $\langle m_{\rm LCP} \rangle$ as well as a larger value of $m_{\rm IMF}$ at which they saturate. At E/A=55 MeV, $\langle m_{\rm IMF} \rangle_{\rm max} \approx 6$ for the most dissipative collisions [2]. Therefore, one expects and observes [4] that $\langle m_{\rm LCP} \rangle$ and $\langle m_n \rangle$ saturate at $m_{\rm IMF} \approx 6$.

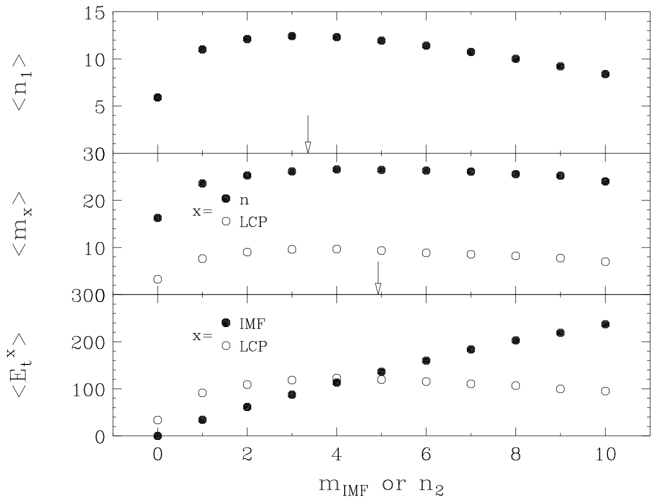

FIG. 1. Top: $\langle n_1 \rangle$ as a function of n_2 for the model described in the text. Middle: $\langle m_n \rangle$ and $\langle m_{\rm LCP} \rangle$ as a function of $m_{\rm IMF}$ predicted by SMM [3]. The arrows show $\langle n_2 \rangle_{\rm max}$ and $\langle m_{\rm IMF} \rangle_{\rm max}$. Bottom: $\left\langle E_t^{\rm IMF} \right\rangle$ and $\left\langle E_t^{\rm LCP} \right\rangle$ as a function of $m_{\rm IMF}$ predicted by SMM.

For point 2), the authors argue that the continuous rise of $\left\langle E_t^{\rm IMF} \right\rangle$ with $m_{\rm IMF}$ helps prove that the IMFs have not competed with the LCPs for the thermal energy of the system. However, $\left\langle E_t^{\rm IMF} \right\rangle$ will *by definition* rise with increasing $m_{\rm IMF}$ *regardless* of the IMFs' dynamical or statistical origin. This is so since $\left\langle E_t^{\rm IMF} \right\rangle = \left\langle \sum_{i=1}^{m_{\rm IMF}} E_i \sin^2 \theta_i \right\rangle \approx m_{\rm IMF} \left\langle \epsilon_t^{\rm IMF} \right\rangle$, where $\left\langle \epsilon_t^{\rm IMF} \right\rangle$ is the average transverse energy of an IMF. The corresponding trends from SMM are shown in Fig. 1 and are consistent with those observed in ref. [1].

In summary, the observations listed above are *fundamental features* of statistical decay and as such, do not display the dramatic failure that would be necessary to justify invoking dynamic IMF production. While the IMFs may be produced dynamically, such a claim is not supported by the experimental observations listed above. Without a strong and clear cut failure of the statistical models, the declared need for new physics is unwarranted.

[1] J. Toke *et al.*, Phys. Rev. Lett. **77**, 3514 (1996).
[2] W. Skulski *et al.*, Rochester Prog. Rep., DOE/ER/40414-8, 1995.
[3] J.P. Bondorf, *et al.*, Phys. Rep. **257**, 133 (1995).
[4] W.U. Schröder, Rochester Prog. Rep., DOE/ER/40414-9, 1996.